Langley

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

AUG 21 1974

REPLY TO ATTN OF: GP

TO: KSI/Scientific & Technical Information Division
Attn: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures agreed upon by Code GP and Code KSI, the attached NASA-owned U.S. Patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

| | |
|---|---|
| U.S. Patent No. | : 3,828,524 |
| Government or Corporate Employee | : U.S. Government |
| Supplementary Corporate Source (if applicable) | : |
| NASA Patent Case No. | : LAR-10,194-1 |

NOTE - If this patent covers an invention made by a corporate employee of a NASA Contractor, the following is applicable:

YES ☐ NO ☒

Pursuant to Section 305(a) of the National Aeronautics and Space Act, the name of the Administrator of NASA appears on the first page of the patent; however, the name of the actual inventor (author) appears at the heading of column No. 1 of the Specification, following the words "...with respect to an invention of ..."

Bonnie L. Woerner

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Enclosure

# United States Patent [19]

**Booth et al.**

[11] **3,828,524**

[45] **Aug. 13, 1974**


[54] **CENTRIFUGAL LYOPHOBIC SEPARATOR**


[75] Inventors: **Franklin W. Booth,** Hampton; **Robert A. Bruce,** Newport News, both of Va.

[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration,** Washington, D.C.



[22] Filed: **Aug. 9, 1971**

[21] Appl. No.: **169,962**

[52] **U.S. Cl.** .......................... **55/43,** 55/159, 55/199

[51] **Int. Cl.** .......................................... **B01d 19/00**

[58] **Field of Search** ........... 55/36, 52, 55, 199, 421, 55/431, 432, 400, 408, 43, 159; 233/2, 13, 16, 32, 44


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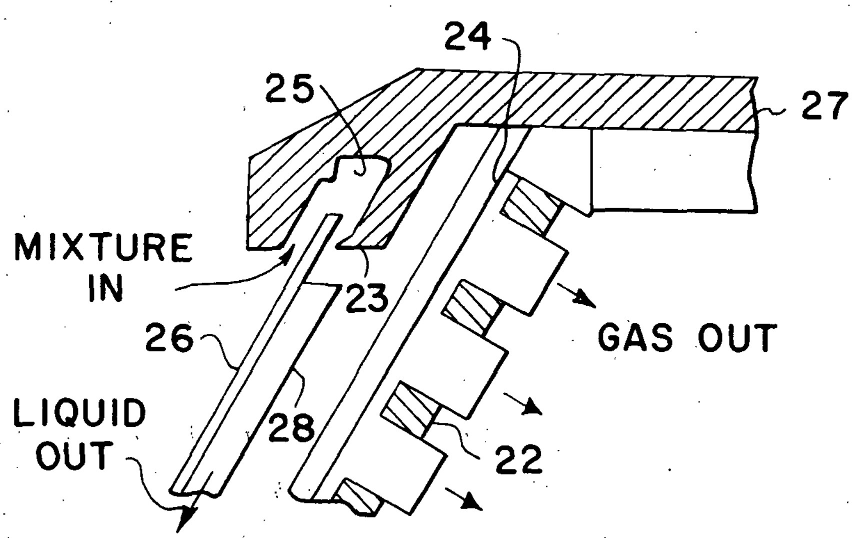
[57] **ABSTRACT**

A centrifugal separator using a lyophobic filter for removing liquid particles from a mixed stream of gas and liquid under various negative or positive external acceleration conditions as well as zero *g* or weightless conditions. Rotating the lyophobic filter and inclining the filter to the entering flow improves the lyophobic properties of the filter, provides gross separation of larger liquid particles and prevents prolonged contact of liquid droplets with the spinning filter which might change the filter properties or block the filter.


**33 Claims, 5 Drawing Figures**



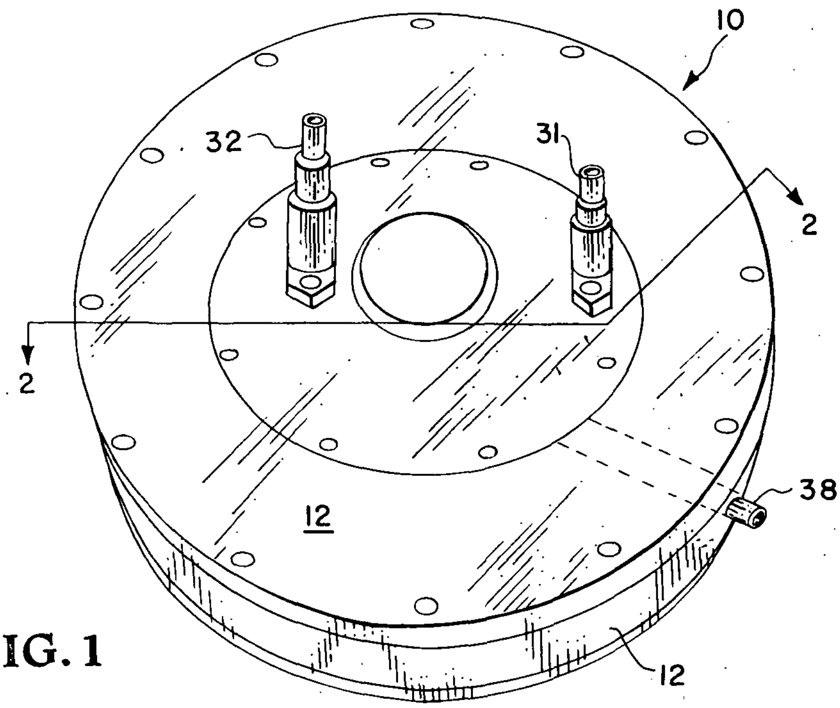



FIG. 1

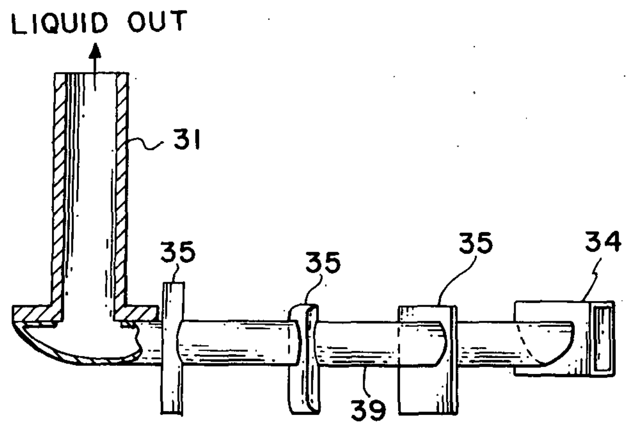



FIG. 4

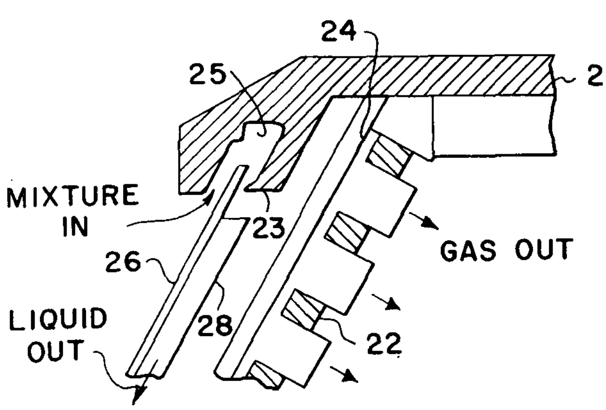



FIG. 3

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PATENTED AUG 13 1974 3,828,524



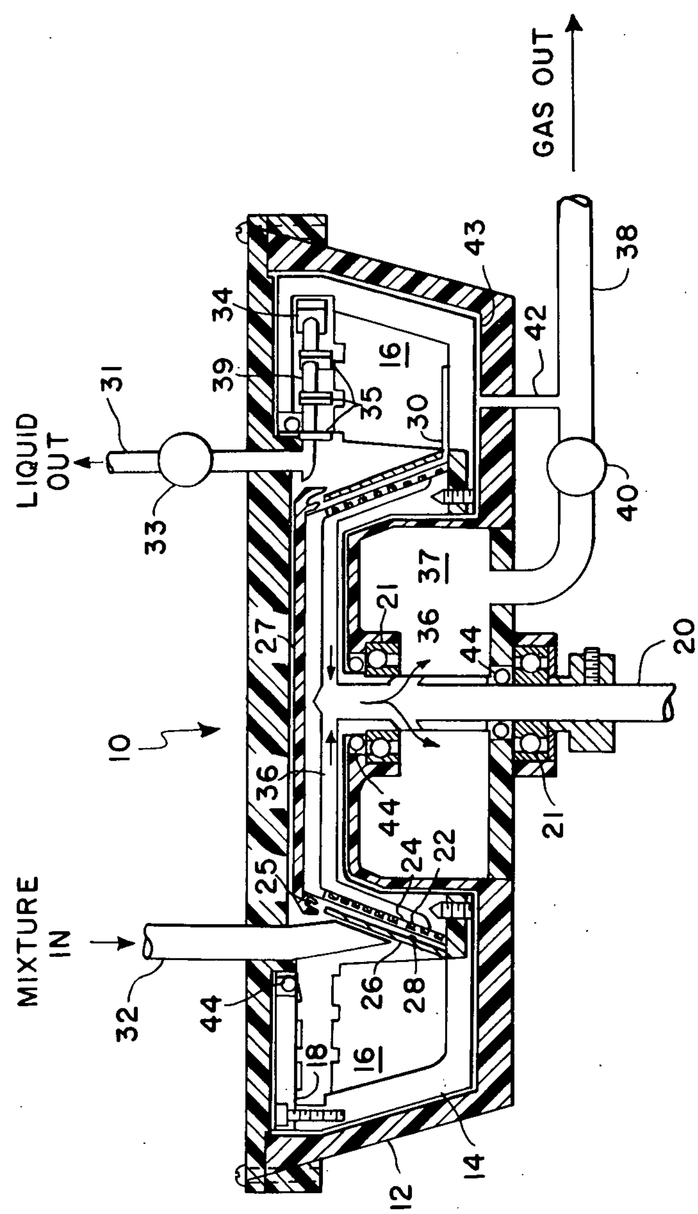


FIG. 2

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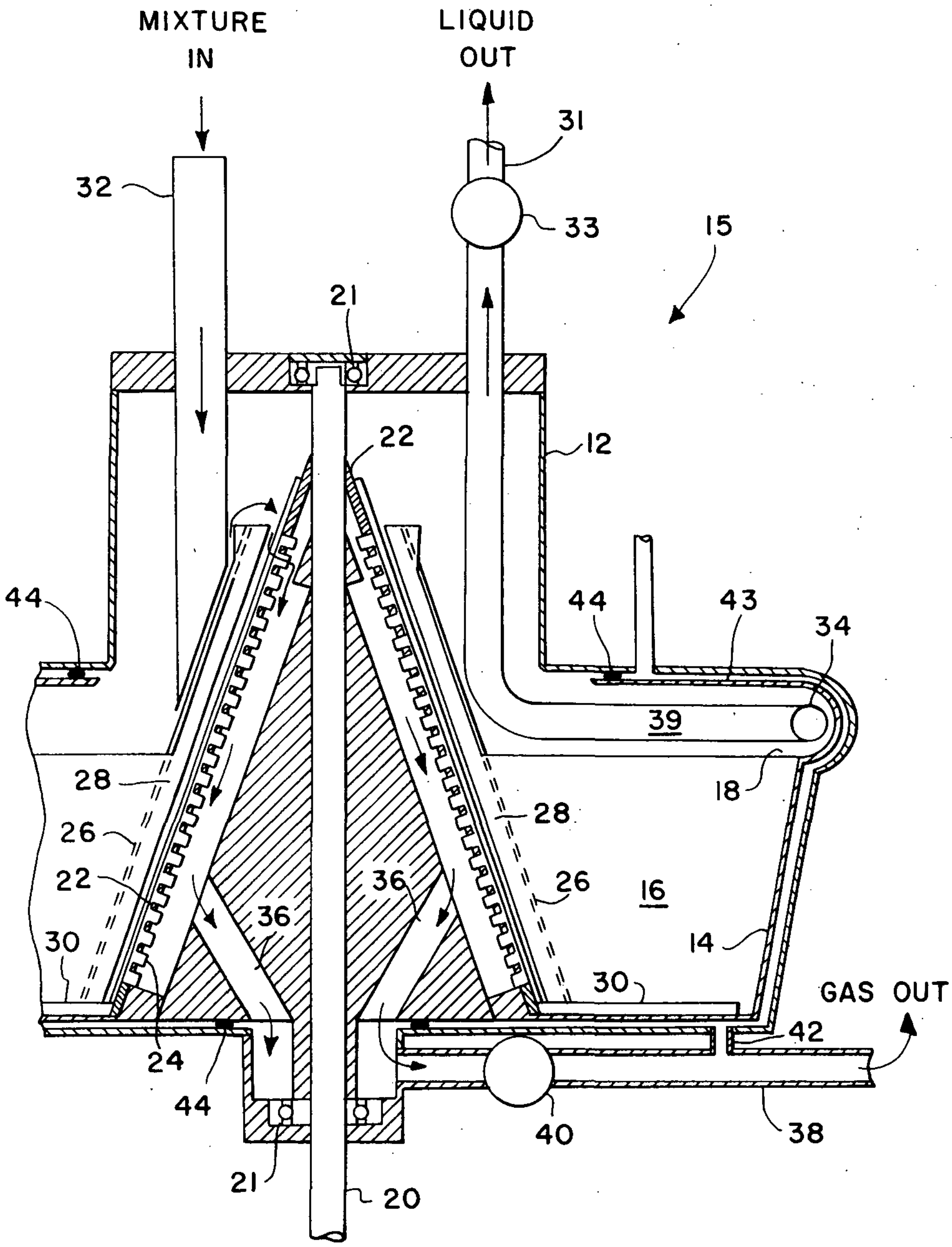


FIG. 5

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# CENTRIFUGAL LYOPHOBIC SEPARATOR

## ORIGIN OF THE INVENTION

The invention described herein was made by employees of the National Aeronautics and Space Administration and may be used and manufactured by the Government for governmental purposes without the payment of any royalties thereon or therefor.

## BACKGROUND OF THE INVENTION

This invention relates to a centrifugal separator and more particularly to a separator of aerosols from a mixed stream of gas and liquid utilizing both centrifugal force and a lyophobic filter. The use of lyophobic filters to separate liquid aerosols from a gas stream is known in the art. Using both lyophobic filtration and centrifugal force however, has several advantages over the use of either method of separation by itself.

Some liquids can convert to a lyophobic material to a lyophilic material after several minutes of surface contact. Urine, for example, forms a protein deposit upon lyophobic material which gives the material lyophilic properties. Rotating the filter produces centrifugal force which can prevent contact between the lyophobic filter and liquid particles which might alter the lyophobic properties of the filter. Rotation also provides gross separation of the heavier liquid particles and concentration of the smaller particles.

Manned spacecraft life support systems must collect urine during flights, such as that planned for PROJECT SKYLAB. The urine, which is collected and transported by means of an airstream, must be efficiently separated from the air in a zero gravity ($g$) environment for measurement and sampling and for the potential reprocessing of urine to potable water on future, longer duration missions. The air must not contain urine aerosols since the air is eventually recirculated through the spacecraft cabin for breathing. The need for efficient separation of the urine from the airstream, the effect of prolonged contact between the urine and the lyophobic filter, and the zero $g$ conditions of space led to the design of the novel separator described herein.

## SUMMARY OF THE INVENTION

The novel separator includes a stator body through which inlet and exit lines pass. Within the stator, connected to and disposed about a rotating shaft are a container with inclined walls leading to a collector cavity, a deflector cone having capillary channels at its base, a truncated conical lyophobic filter within the deflector cone and suction air exit passages leading to an air exit line and suction pump.

The inlet flow, comprised of liquid transported by a gas, enters the rotating container. The outer surface of the deflector cone deflects the droplets in the entering mixture and prevents immediate contact with the lyophobic filter. The heavier aerosols are immediately made to flow outward to the outer container walls after contacting the spinning deflector cone. The remaining gas mixture then circulates to enter an opening between the deflector cone and the conical lyophobic filter. The lip of this opening is shaped to deflect larger liquid particles toward the inner wall of the deflector cone. Any liquid droplets contacting the filter will immediately be flung outward against the inside surface of the deflector cone. Vanes on the inner surface of the deflector cone channel the liquid to the base of the cone where the liquid escapes through capillary channels in the cone to the sides of the cup. The capillary channels are designed for outflow only and liquid in the container cannot flow back through these openings. Blades within the container guide the liquid to the collecting cavity where the liquid is forced to exit the cup via a pitot exit tube. A check valve in the line from the pitot exit tube maintains a backpressure against the escaping liquid. Positive liquid pressure is required to open the check valve thus preventing the escape of gas or gas mixture from the container through the pitot. To prevent splashing from the pitot exit tube directly into the opening between the deflector cone and the filter, fins shaped to direct any splash toward the outer container wall are placed on a radial arm portion of the pitot exit tube.

The gas from the gas mixture is drawn through the lyophobic filter and through suction air exit passage by a blower. The blower also serves to pressurize the sealed space between the stator and rotor so that the stator and rotor seals will not leak fluid.

Rotation of a lyophobic filter improves the lyophobic properties of the filter. Centrifugal force at the filter surface acts to oppose passage of liquid droplets through the filter and thus is, in effect, equivalent to an increase in the tensile holding strength of the liquid interface in the pores of the filter. This equivalent increase in tensile strength or increased negative capillary force resists the differential motive force of the liquid droplets more effectively than if the filter were stationary. Moreover, the vector resolution of the mixture velocity as it impinges at a point on the filter and the tangential velocity of the point due to filter rotation results in an acute angle of flow impact. This acute angle of flow impact means that the effective pore size, as seen by the flow, is decreased. A smaller effective port size and more equivalent liquid surface tensile holding power results in improved lyophobic properties in the filter.

When the surface of the rotating filter is inclined to the flow, some further gains in reduced effective pore size are realized with lower rotational speeds. Areas of the filter which are near the axis of rotation are blocked to prevent filtration in areas of low centrifugal force and large effective pore size. For example, the lyophobic filter might comprise the sloping sides of the frustum of a cone rotated about its conic axis rather than the entire cone since the apex area would experience little centrifugal force.

The advantages of the present invention are made obvious by a consideration of results. In current tests, less than 1 percent air (approximately one quarter of 1 percent) has been found in the separated liquid while no measurable amounts of liquid can be found in the escaping airstream.

The present invention has been operated successfully in all orientations in a normal $1g$ field, as well as in zero gravity aircraft trajectories, and the separator is believed capable of a wider range of operating $g$ load.

It is therefore an object of the present invention to provide a simple, compact, lightweight separator for aerosols from a gaseous stream having a high efficiency which avoids prolonged contact with the liquid to be separated and is unaffected by $g$ loading. It is a further object of the invention to improve the properties of a

lyophobic filter so as to restrict the passage of smaller liquid droplets for a given pore size and to restrict the passage of liquid at a higher liquid droplet motive force.

## BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the invention and many of the attendant advantages thereof will be readily apparent as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 is a perspective view of the preferred embodiment of the novel separator;

FIG. 2 is a sectional view of the preferred embodiment taken along section line 2—2 of FIG. 1;

FIG. 3 is a detailed view of the cusped cavity surrounding the upper edge of the deflector on the preferred embodiment;

FIG. 4 shows a detail view of the liquid pitot collector and splash suppressing vanes;

FIG. 5 is a cross-sectional view of another embodiment of the invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now more particularly to the drawings wherein the numerals designate identical parts throughout the several views, and more particularly to FIG. 1, there is shown the novel separator **10** having a stator housing **12**, a mixture inlet **32**, a liquid exit line **31**, and a gas outlet line **38**.

The cross-sectional view in FIG. 2 of the novel separator **10** shows the stator housing **12**, and a rotating annular container **14** containing several blades **16** positioned perpendicular to the container and radially alined and distributed within the container **14**. Container **14** is rotated by a shaft **20** which turns in bearings **21**. A lyophobic filter **24** is carried by a core **22** that is surrounded by a deflector **26**, all of which rotate with container **14**. Deflector **26** has vanes **28** on its inner surface and the upper edge of deflector **26** projects into a cusped cavity **25** of cap **27** (see FIG. 3). At the base of deflector **26**, capillary drain channels **30** provide openings through the deflector walls of the container proper. Suction air passages **36** are located behind filter support member **22** and lead to an annular gas chamber **37**, a gas outlet line **38** and suction pump **40**. A liquid pitot collection **34** having vanes **35** located on radial-arm portion **39** collects the liquid accumulating in collecting cavity **18**. Liquid exit line **31** and a 5 inches-of-water backpressure device **33** receive fluid from pitot collector **34**. A space **43** between stator **12** and container **14** is sealed by seals **44** and is pressurized by pressure line **42** from gas outlet **38**.

FIG. 3 shows cusped cavity **25** in more detail. Cusped cavity **25** partly encloses an edge of deflector **26** having vanes **28**. The liquid-gas mixture circulates between the filter and the deflector via cusped cavity **25** in cap **27**. Filter **24** is attached to cap **27**. A cusp **23** forms a protruding lip at the inner edge of the annular cusped cavity **25**. Vanes **35** are shown located on the radial arm portion **39** of pitot collector **34** in FIG. **4**, and liquid exit line **31** is also shown. FIG. **5** shows an alternate embodiment **15** wherein filter **24** and deflector **26** come to more of a point.

## OPERATION

The operation of the novel separator is now believed apparent. Container **14** is rotated by shaft **20**. A mixture of gas and liquid enters mixture inlet line **32** where the flow impinges upon the outer surface of deflector cone **26**. This flow is directed onto the outer surface of the deflector cone **26** in such a manner that the most of the liquid flows smoothly onto the surface of the cone. This liquid film flows along the surface of the cone **26** in the direction of the larger cone diameter and then along the adjacent surfaces of the rotating container to the collection cavity **18**. This process minimizes splatter and the formation of additional aerosols within the separator. The gas and aerosol mixture is made to rotate by the blades **16** within the rotating container **14** and the heavier aerosols are moved to the outer surface of container **14**. Smaller droplets remaining in the flow circulate around the upper edge of deflector cone **26** through cusped cavity **25**. The cusp **23** on the inner lip of cavity **25** directs most of the droplets in the flow against the inner surface of deflector cone **26**. Vanes **28** on the inner surface of deflector cone **26** channel the liquid to the bottom of the cone. Any liquid striking lyophobic filter **24** will likewise be deflected against the vaned inner surface of deflector cone **26**.

Liquid at the bottom of the deflector cone **26** escapes radially through drain channels **30** which are capillaries. The capillary force of the channels **30** can only be overcome by centrifugal force so that flow is one way and no liquid passes from the container **14** back into the deflector cone **26** after rotation stops. Liquid is channeled to the container wall by the blades **16** and collects in the collecting cavity **18**. A stationary liquid pitot collector **34** collects this liquid for transmission through liquid exit line **31**. Backpressure device **33** maintains a back-pressure of 5 inches-of-water which must be overcome by liquid pressure thus preventing the flow of the gas or gas mixture through liquid exit line **31**. Since radial arm portion **39** of pitot collector **34** causes some splashing of the liquid, fins **35** direct the splash back toward the container wall and the collecting cavity **18**, protecting cusped cavity **25** from splash.

The separated gas is pulled through filter **24** into suction air passages **36**, an annular gas chamber **37** and gas outlet line **38** by a blower **40**.

The space **43** between container **14** and stator **12** is sealed by seals **44** and is pressurized by a line **42** from gas outlet line **38**. Since static pressure in container **14** is slightly below the static pressure in the mixture flow, the pressurization source need not be at a very high pressure, and blower output pressure suffices.

The operation of alternate embodiment **15** shown in FIG. **5** is identical to the above. Since the upper portion of the conical lyophobic filter **24** is not blocked in alternate embodiment **15**, some soaking at the top of the filter can result. When urine is the liquid contained in the entering mixture, soaking can convert the filter from lyophobic to lyophilic. Truncating the conical filter and blocking the top of the frustum with cap **27** (separator **10** in FIG. **2**) avoids this problem.

Although the invention has been described and illustrated in detail in specific embodiments thereof, it is to be understood that this description is by way of illustration only and is not to be taken as limiting on applicants' invention. Filter material and porosity may be

matched depending upon the properties of the constituents of the entering mixture and the rotational speed of the centrifugal separator. Average rotational speed used in the particular embodiments shown was 230 rpm, but various rotational speeds could be used depending upon the constituents to be separated.

What is claimed as new and desired to be secured by Letters Patent of the United States is:

1. A centrifugal separator for separating a mixture of gas and liquid comprising: a housing; a rotating member having an axis of rotation disposed within the housing; a nonwettable porous means attached to said rotating member and disposed about said axis of rotation, said nonwettable porous means admitting gas and restricting the passage of liquid through said nonwettable porous means, whereby the gas is completely separated from the liquid and the liquid completely separated from the gas.

2. The centrifugal separator of claim 1 including deflector means attached to said rotating member and spaced from and partially surrounding said nonwettable porous means, said deflector means for shielding said nonwettable porous means from direct contact with the mixture of gas and liquid as the mixture enters said rotating member.

3. The centrifugal separator of claim 2 wherein said deflector means includes drain means for providing one way flow of liquid from within said deflector means outward by centrifugal action to said rotating member.

4. The centrifugal separator of claim 3 wherein said drain means are capillary channels.

5. The centrifugal separator of claim 3 wherein said deflector means includes an inner surface and said inner surface includes guide means for channeling liquid over said inner surface.

6. The centrifugal separator of claim 1 including cap means attached to said nonwettable porous means, said cap means blocking an area of said nonwettable porous means near said axis of rotation.

7. The centrifugal separator of claim 6 including deflector means attached to said rotating member and spaced from and partially surrounding said nonwettable porous means, said deflector means for shielding said nonwettable porous means from direct contact with the mixture of liquid and gas entering said rotating member and wherein said cap means includes a cavity partly enclosing an edge of said deflector means and cusp means projecting into said cavity, said cusp means for directing the flow of the mixture circulating between said deflector means and said nonwettable porous means, whereby the liquid droplets entering the cavity are directed against the inside of the deflector means.

8. The centrifugal separator of claim 1 wherein the housing surrounding said rotating member does not rotate; a space between said housing and said rotating member; seal means located between said housing and said rotating member for preventing the passage of fluid between said rotating member and said space; gas outlet means attached to said housing for removing gas passing through said nonwettable means; and pressure seal line means connecting said space and said gas outlet means, said pressure seal line means for pressurizing said space and for preventing the passage of fluid from said rotating member into said space.

9. The centrifugal separator of claim 1 including liquid pitot collector means disposed within said rotating member and for removing liquid from said rotating member, said liquid pitot collector means including means for creating a backpressure, whereby a positive liquid pressure is required for liquid exit from said rotating member and gas may not escape said rotating member through said liquid pitot collector means.

10. The separator of claim 1 wherein said nonwettable porous means includes a surface, said surface being three-dimensionally shaped.

11. The separator of claim 10 wherein said surface comprises a body of revolution having an axis along said axis of rotation.

12. The separator of claim 10 wherein said surface forms a truncated cone.

13. The separator of claim 10 including deflector means attached to said rotating member and for shielding said nonwettable porous means from direct contact with the mixture of gas and liquid entering said rotating member.

14. The centrifugal separator of claim 13 wherein said deflector means includes drain means for providing one way flow of liquid from within said deflector means to said rotating member.

15. The centrifugal separator of claim 14 wherein said deflector means includes an inner surface and said inner surface includes guide means attached to said inner surface for channeling liquid over said inner surface whereby the liquid passes through said drain means into said rotating member.

16. The centrifugal separator of claim 15 including cap means attached to said nonwettable porous means, said cap means for blocking an area of said nonwettable porous means near said axis of rotation, said cap means including a cavity partly enclosing an edge of said deflector means and cusp means projecting into said cavity, said cusp means for directing the flow of the mixture circulating between said deflector means and said nonwettable porous means, whereby the liquid droplets entering the cavity are directed against said inner surface.

17. The centrifugal separator of claim 16 wherein said housing does not rotate and surrounds said rotating member; a space between said housing and said rotating member; seal means located between said housing and said rotating member for preventing the passage of fluid between said rotating member and said space; gas outlet means attached to said housing for removing gas passing through said nonwettable porous means; pressure seal line means connecting said space and said gas outlet means, said pressure seal line means for pressurizing said space and for preventing the passage of fluid from said container member into said space; liquid pitot collector means disposed within said rotating member and for removing liquid from said rotating member, said liquid pitot collector means including means for creating a backpressure, whereby a positive liquid pressure is required for liquid exit from said rotating member and gas may not escape said rotating member through said liquid pitot collector means.

18. The centrifugal separator of claim 17 wherein said surface forms a truncated cone, said drain means are capillary channels and said guide means are vanes projecting from said inner surface.

19. A method of improving the lyophobic efficiency of lyophobic filter subjected to a flow of a mixture of

gas and liquid having a flow direction comprising the step of: rotating the lyophobic filter about an axis of rotation; whereby the equivalent filter pore size as seen by the flow is decreased.

**20.** The method of claim **19** including the further step of inclining the surface of the lyophobic filter such that the surface is approximately perpendicular to the flow direction.

**21.** The method of claim **19** including the further step of inclining the surface of said lyophobic filter such that the surface and the flow direction form an acute angle.

**22.** The method of claim **19** including the further step of blocking the surface of said rotating lyophobic filter near said axis of rotation to prevent areas of the filter surface experiencing low centrifugal force from filtering the mixture.

**23.** The method of claim **21** including the further step of blocking the surface of said rotating lyophobic filter near said axis of rotation to prevent an area of the filter surface experiencing low centrifugal force from filtering the mixture.

**24.** A method of separating gas and liquid from a mixture of gas and liquid comprising the steps of: providing a flow of the mixture having a flow direction: interposing a lyophobic filter in said flow to filter the liquid out of the mixture, rotating said filter about an axis of rotation to improve the lyophobic properties of the filter; and recovering essentially pure gas and essentially pure liquid ingredients of the mixture.

**25.** The method of claim **24** including the further step of inclining the surface of the lyophobic filter approximately perpendicular to the flow direction.

**26.** The method of claim **24** including the further step of inclining the surface of the lyophobic filter at an acute angle to the flow direction.

**27.** The method of claim **24** including the further step of blocking the surface of said lyophobic filter near said axis of rotation to prevent an area of the filter experiencing low centrifugal force from filtering the mixture.

**28.** The method of claim **24** including the further steps of shielding the lyophobic filter with a deflector from direct contact by the flow; and circulating the mixture after said mixture has struck the deflector, through a space between the deflector and the filter.

**29.** The method of claim **28** including the further step of depositing the flow of the mixture against said deflector in such a manner as to minimize splatter.

**30.** The method of claim **28** including the further step of rotating the deflector to provide gross separation of liquid, whereby the heavier liquid droplets entering the separator are made to flow outward by contact with the outer surface of the deflector and recovered in a container.

**31.** The method of claim **30** including the further steps of depositing the flow of the mixture against said deflector in such a manner as to minimize splatter, trapping the liquid thrown outward by the rotating lyophobic filter against the inner surface of said deflector and channeling the liquid within said deflector into a container.

**32.** The method of claim **31** including the further step of blocking the surface of said lyophobic filter near said axis of rotation to prevent an area of the filter experiencing low centrifugal force from filtering the mixture.

**33.** The method of claim **32** including the steps of providing a rotating container, a fixed housing surrounding said container, and a seal between said container and said housing; pressurizing said seal to prevent the mixture or any ingredient from escaping said container; providing a liquid exit; and restricting the recovery of separated liquid through said liquid exit so that a positive pressure is required for recovery of the liquid whereby gas cannot escape through the liquid exit.

* * * * *